Quarterly Progress Report 3 | *Covering the period 1 December 1962 to 28 February 1963*

OBJECTIVE AND DYNAMICAL STUDIES OF TROPICAL WEATHER PHENOMENA

Prepared for:

U.S. ARMY ELECTRONIC RESEARCH AND DEVELOPMENT LABORATORY
FORT MONMOUTH, NEW JERSEY

CONTRACT DA 36-039 SC-89092
PROJECT 3A99-27-025-09-00

STANFORD RESEARCH INSTITUTE

MENLO PARK, CALIFORNIA

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By: *R. L. Mancuso* *R. M. Endlich*

SRI Project No. 4129

Objective: To carry out research leading to the development of objective methods of analyzing and forecasting tropical weather, and concerning the dynamics of tropical circulations.

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CONTENTS

LIST OF ILLUSTRATIONS iii

LIST OF TABLES iii

PURPOSE iv

ABSTRACT v

I PUBLICATIONS, LECTURES, REPORTS, AND CONFERENCES 1

II FACTUAL DATA 2

A. Task 1 2

B. Task 2 2

C. Task 3 10

III PROGRAM FOR THE NEXT QUARTER 13

IV PERSONNEL 14

ABSTRACT CARD

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ILLUSTRATIONS

Fig. 1	Stream-Function Analysis for Layer II (850-700 mb) at 1200 GCT, 8 May 1959.	5
Fig. 2	Wind-Contour Analysis (Portig) for 775-mb Level . .	5
Fig. 3	Stream-Function Analysis for Layer V (350-200 mb) .	6
Fig. 4	Wind-Contour Analysis (Portig) for 250-mb Level . .	6
Fig. 5	Contour Analysis for Layer II (850-700 mb).	7
Fig. 6	Contour Analysis for Layer V (350-200 mb)	7
Fig. 7	Vertical Motions (700 mb), Relative Humidity (Layer II) and Surface Weather.	9

TABLES

Table I	Comparison of Height (z) versus Stream Function (ψ) for 5-8 May 1959 (30 Caribbean Stations). . . .	8
Table II	Average Magnitudes of Vorticity, Divergence, and Deformation for 5-8 May 1959 (30 Caribbean Stations)	11

PURPOSE

The purpose of this research is to furnish knowledge that can be used in the development of objective methods of analyzing and forecasting tropical weather and in understanding the dynamics of tropical weather phenomena. It is planned that the objective techniques will be designed for electronic computation in order to gain speed and accuracy, and to reduce personnel requirements in an operational situation. The investigations are divided into the following tasks:

(1) Analyze the three-dimensional structure, the changes with time, the movement, and the surface weather, of selected cases of representative meteorological phenomena, by using conventional methods. If practicable, Tiros data will be included in the analysis.

(2) Investigate and, insofar as possible, develop objective analysis techniques applicable to tropical phenomena and compare the objective analyses with the analyses of Task (1) above.

(3) Utilizing the analyses of Tasks (1) and (2) above, carry out dynamical studies of such topics as the forces predominant in various phenomena, the conservation of fields of vorticity, divergence and deformation, and the importance of orography and low-level energy inputs.

ABSTRACT

During the third quarter, analyses of the objectively computed layer quantities (relative humidity, stream function, divergence, etc.) for the period 5-8 May 1959 were completed. The degree of persistence of the stream function was investigated and found to be considerably greater than that of heights during this period. The stream function fields were also compared with subjective wind-contour charts independently prepared by Dr. Portig of the University of Texas, and showed excellent agreement. The vertical motion and humidity fields were compared with surface reports of clouds and precipitation, and were found to be in reasonably good agreement. The limited coverage provided by surface reports is a definite handicap to such comparisons, and indicates that further evaluations should be made with satellite data. Investigation of the influence of scale (size of computational triangles) on computed values of divergence and vorticity revealed that magnitude decreased, on the average, by about one-half, as area increased from 2×10^4 to 4×10^5 km^2. Beyond this size, average magnitudes remained constant in an unrealistic fashion. Thus it appears that an upper limit of size is approximately 4×10^5 km^2, for computations of this type.

I PUBLICATIONS, LECTURES, REPORTS, AND CONFERENCES

Publications, Lectures, and Reports

An abstract entitled "An Objective Stream Function for Tropical Analysis," has been submitted to the Third Technical Conference on Hurricanes and Tropical Meteorology to be held at Mexico City in June 1963. This paper will review the stream function technique developed in this contractual work and will generally follow the material presented in the Quarterly Reports.

Conferences

During the second Western National Meeting of the AGU (27-29 December), Lt. Col. James E. Sadler of the National Science Foundation (Indian Ocean Expedition) visited the Institute. The applications of satellites and numerical techniques to tropical meteorology were discussed.

Mr. Marvin Lowenthal of the U.S. Army Electronics Research and Development Laboratory visited the Institute on 28 January 1963. During his visit, the work performed under the contract was reviewed and evaluated, and general plans were made for the remainder of the contractual period.

II FACTUAL DATA

A. Task 1

The processing, mapping, and analysis of radiosonde data for the Caribbean during the period 5-8 May 1959 have been completed in the form of layer averages of height, temperature, relative humidity, and wind components. Several examples of these data have already been illustrated in previous Quarterly Reports. The relative humidity has been particularly revealing, and the heights and winds have been valuable for objectively computing the stream function discussed in Task 2. A more detailed discussion of these layer-averaged data and the general atmospheric motions and structure for this period will be deferred to the Final Report.

B. Task 2

1. Stream-Function Routine

In the Second Quarterly Report the development of an objective method for computing a stream function ($\overset{*}{\psi}$) was discussed in some detail. The technique used was to successively correct an initial guess (observed height data) in accordance with the equation

$$\overset{*}{\psi}_o = \overset{*}{\psi}_i + \frac{(f_o + f_i)}{4g} \left[(v_o + v_i)\ (x_o - x_i) - (u_o + u_i)\ (y_o - y_i) \right] \qquad (1)$$

where u and v are wind components, f is the Coriolis parameter, g is gravity, the subscript o denotes the station of interest and i denotes a neighboring station. An insight into the workings of the procedure may be gained by applying Eq. (1) to a hypothetical group of stations arranged in a rectangular grid. Station o is at the center, station 1 lies a distance d to the east, station 2 lies similarly to the north, 3 to the west, and 4 to the south. Equation (1) is written for relating

station o with each of the four neighbors (i = 1, 2, 3, 4). For example for i = 1 and f considered constant

$$\overset{*}{\psi}_o = \overset{*}{\psi}_1 + \frac{f}{2g}(v_o + v_1)(-d) \quad . \tag{2}$$

The four relations for i = 1, 2, 3, 4 are then summed, giving

$$4\overset{*}{\psi}_o = \sum_{i=1}^{4} \overset{*}{\psi}_i - \frac{fd^2}{g}\left[\frac{(v_1 - v_3)}{2d} - \frac{(u_2 - u_4)}{2d}\right] \quad . \tag{3}$$

The quantity in brackets is a finite-difference expression for vorticity (obtained from observed wind components) and $\sum \overset{*}{\psi}_i - 4\,\overset{*}{\psi}_o$ is a finite-difference form of the Laplacian for the stream function. Viewed in this way, the stream-function procedure utilizes vorticity given by observed winds, along with values of $\overset{*}{\psi}_i$ given initially by height data, in order to compute $\overset{*}{\psi}_o$. This usage may be contrasted to that in extra-tropical meteorology where Eq. (3) is used to obtain vorticity from values of height.

The stream-function procedure is fast, fairly insensitive to data distribution, operates quite well when data are missing, and could easily incorporate aircraft, constant-level balloon, or satellite wind data. Stream-function fields for the Caribbean area have been computed for the period 5-8 May 1959.

One of the advantages of a stream function having the units of meters is that it permits comparison with subjective contour analysis. Dr. Wilfried H. Portig and associates, of the University of Texas, who have considerable experience in tropical meteorology, have prepared contour maps for the same period (5-8 May 1959). Comparisons between these independently produced analyses and the stream-function fields for this period are presently being conducted. It is our understanding

that Dr. Portig's technique is based primarily on winds and their time continuity and to a lesser degree on heights corrected by use of thickness charts. His analyses for the 775-mb and 250-mb levels--in close but not identical correspondence to the Layers II and V of Figs. 1 and 3--are illustrated in Figs. 2 and 4. As can be seen by comparing Fig. 1 with Fig. 2 and Fig. 3 with Fig. 4, there is excellent agreement, while both are significantly in disagreement with the observed (uncorrected) heights shown in Figs. 5 and 6. Other comparisons of the two methods of analysis have also shown excellent agreement. Any discrepancies noted could be attributed to the differences between layer and constant-level winds or to the subjectivity involved in both analyses over areas of sparse data.

One of the qualities sought in a meteorological quantity is persistence--that is, that it be valid for a certain period of time. In order to investigate the persistence of the stream function and of reported heights, the root-mean-square changes and correlations over various time intervals have been computed. The correlation coefficient is particularly revealing because it eliminates consideration of the variations of the mean fields. The results for Layers II and V derived from the eight synoptic times under investigation are tabulated in Table I. It is quite apparent from this table that the stream function possessed considerably greater persistence (correlation coefficients between 0.72 and 0.96) than did the height (correlation coefficients between 0.72 to 0.86). This difference in persistence was particularly noticeable in Layer V.

2. Triangle Routine

With this triple-station computation routine, fields of vorticity, divergence, vertical motion, deformation, and geostrophic departures have been prepared for the period 5-8 May 1959. The results appear very promising for portraying the intrinsic properties of the atmosphere. The vorticity in particular has shown excellent agreement with the stream-function fields. The divergence and associated vertical motions are more difficult to assess because they are more susceptible

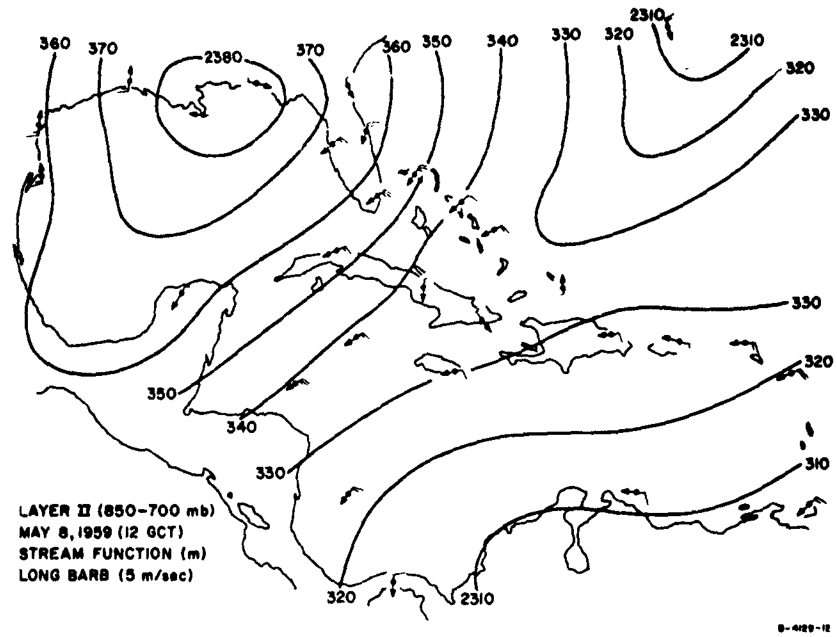

FIG. 1 STREAM-FUNCTION ANALYSIS FOR LAYER II (850-700 mb) AT 1200 GCT, 8 MAY 1959

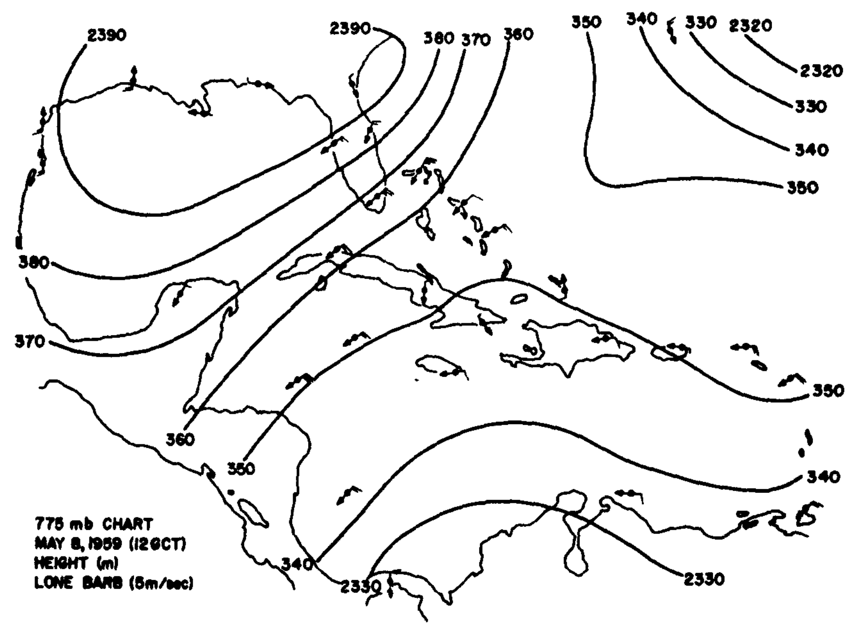

FIG. 2 WIND-CONTOUR ANALYSIS (Portig) FOR 775-mb LEVEL

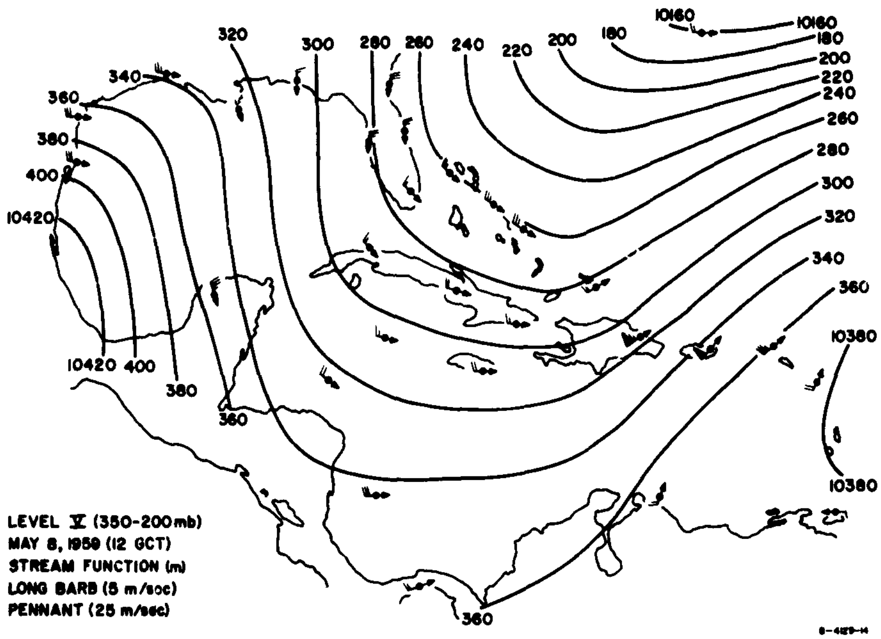

FIG. 3 STREAM-FUNCTION ANALYSIS FOR LAYER V (350-200 mb)

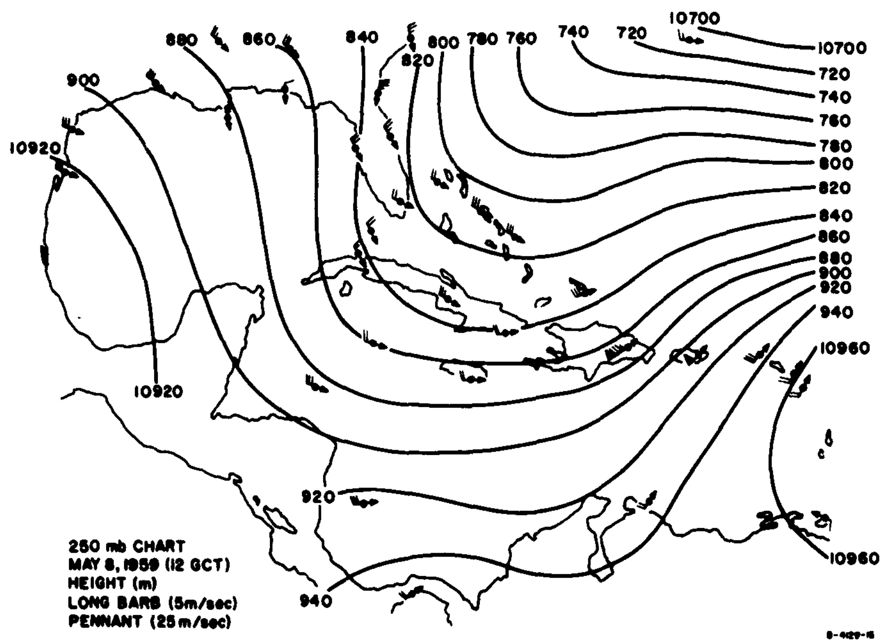

FIG. 4 WIND-CONTOUR ANALYSIS (Portig) FOR 250-mb LEVEL

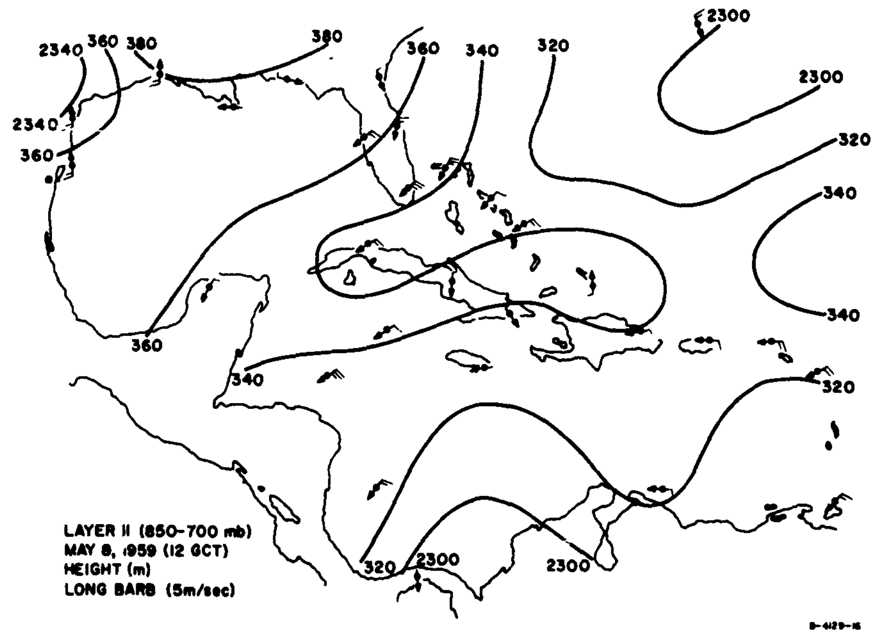

FIG. 5 CONTOUR ANALYSIS FOR LAYER II (850-700 mb)

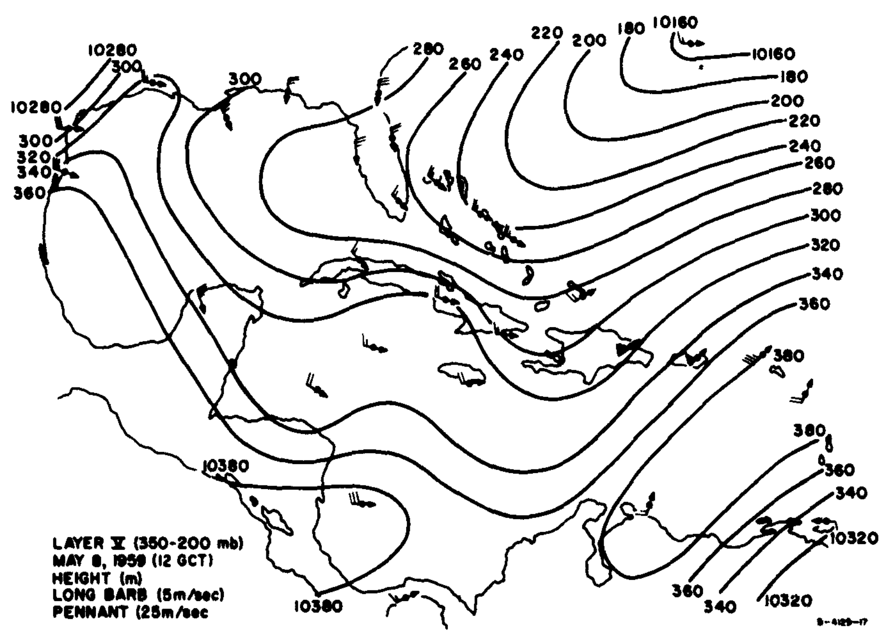

FIG. 6 CONTOUR ANALYSIS FOR LAYER V (350-200 mb)

Table I

COMPARISON OF HEIGHT (Z) VERSUS STREAM FUNCTION (ψ^*) FOR 5-8 MAY 1959

(30 Caribbean Stations)

Layer	Period (hours)	Root-Mean-Square Change (meters)		Correlation	
		Z	ψ^*	Z	ψ^*
II (850-700 mb)	12	13	10	0.80	0.92
	24	16	16	0.81	0.87
	36	23	24	0.75	0.80
	48	30	33	0.72	0.72
V (350-200 mb)	12	32	19	0.73	0.96
	24	40	27	0.86	0.96
	36	51	35	0.79	0.94
	48	55	43	0.80	0.92

to erroneous and unrepresentative winds. The positive vertical motions of the lower layers have shown general agreement with bad weather and low cloud build-up, although positive vertical motions when in combination with very low humidities had correspondingly good weather. One must realize that vertical motion is simply one factor in the production of weather; humidity, stability, advection, among other factors, also need to be considered. The computed vertical motions at 700 mb on 6 May 1959 (1200 GCT) are shown in Fig. 7, along with the humidity patterns of Layer II and the surface weather information. This chart, although the worst of the four-day series, still shows reasonable agreement between the three patterns. An interesting feature of Fig. 7 is that considerable land-sea activity was occurring along the coastal regions of Mexico and Central America. Unfortunately, these observations fell outside the radiosonde network. It is believed that a reasonably

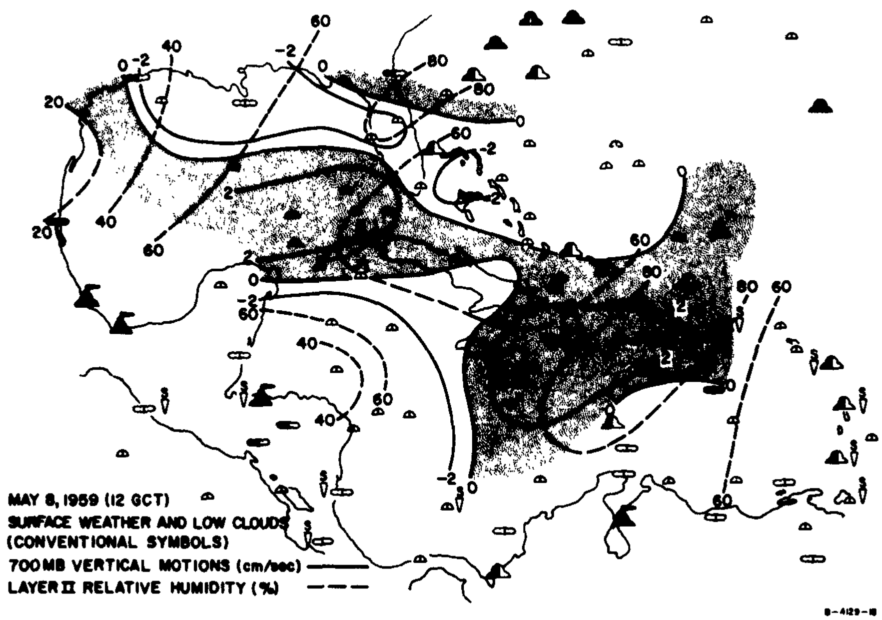

FIG. 7 VERTICAL MOTIONS (700 mb), RELATIVE HUMIDITY (Layer II) AND SURFACE WEATHER

definitive evaluation of kinematic vertical motions can only be made by comparing them to satellite cloud photos and to vertical motions computed by other methods. It is hoped that these comparisons can be carried out in future case studies.

C. Task 3

An important aspect of the triangle computations (vorticity, divergence, etc.) has been the effect of the varying sizes necessitated by the scarcity and unevenness of reporting stations. The question of magnitude of divergence and vorticity versus scale is not only important in the evaluation of the triangle routine, but has considerable bearing upon the extension of numerical forecasting techniques to the tropical regions. The triangles constructed for the computations varied in area from about 10^4 to 10^6 km^2, although 39 of the 43 triangles were smaller than 4×10^5 km^2. The absolute values of the vorticity and divergence for each of these triangles have been averaged over the eight synoptic times under study and over the six different layers. The resulting distributions for both the vorticity and the divergence showed a distinct decrease with increasing area (approximately proportional to the inverse of an effective radius) for triangle areas less than about 4×10^5 km^2. For the larger triangles, computed magnitudes of divergence and vorticity appeared to be constant and not dependent on triangle size. This independence of size is not realistic, for reasons which will be presented in detail in the final report. At this time we will merely mention that the kinematical technique becomes ineffective for triangles having areas much greater than 10^5 km^2.

Average magnitudes of vorticity, divergence and deformation have been computed for the entire period, 5-8 May 1959, for each of the six layers (Table II). The total magnitudes were 1.7×10^{-5} sec^{-1} for vorticity, 0.9×10^{-5} sec^{-1} for divergence, and $1.2 - 1.5 \times 10^{-5}$ sec^{-1} for deformation, the ratio of vorticity to divergence being 1.9.

During the quarter a preliminary experiment was carried out in the use of the streamfunction routine for computing a velocity potential, for the purpose of describing the divergent wind components. If wind

Table II

AVERAGE MAGNITUDE OF VORTICITY, DIVERGENCE, AND DEFORMATION FOR 5-8 MAY 1959 (30 CARIBBEAN STATIONS)

Layer	Vorticity	Divergence	Deformation (Stretching)	Deformation (Shearing)
I	1.0×10^{-5} sec^{-1}	0.7×10^{-5} sec^{-1}	0.9×10^{-5} sec^{-1}	0.9×10^{-5} sec^{-1}
II	1.0	0.8	0.9	0.8
III	1.0	0.6	1.0	0.8
IV	1.6	0.9	1.6	1.1
V	3.2	1.5	2.7	2.0
VI	2.3	1.0	1.8	1.5
I-VI	1.7	0.9	1.5	1.2

vectors are rotated 90° counterclockwise by the operation $\mathbf{k} \times \mathbf{V}$ (where $\mathbf{V} = (\mathbf{k} \times \nabla\psi) + \nabla\chi$) one obtains

$$\mathbf{k} \times \mathbf{V} = (\mathbf{k} \times \nabla\chi) - \nabla\psi \quad . \tag{4}$$

The computer program used previously to obtain ψ can now be used to obtain the potential function χ (with χ constant over the field as a first guess). The results indicate that the rotational wind components are suppressed, but that the divergent and translational components remain. It is believed that the translation property can be omitted by further experimentation.

III PROGRAM FOR THE NEXT QUARTER

The evaluation of the triangle routine and the investigation of the effects of scale will be continued. Further comparisons of objective and subjective analysis are planned. As a result of letter and phone communications with Dr. Portig, we expect that he will visit the Institute, if feasible, for thorough discussions of the two types of analyses.

IV PERSONNEL

Name	Time Devoted to Project This Quarter
R. M. Endlich, Project Leader	Approximately 100 hours
R. L. Mancuso, Research Meteorologist	Approximately 325 hours
J. Weaver, Meteorological Aide	Approximately 190 hours

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layer averages
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stream function
observed winds
observed heights
vorticity
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